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Peterson

THE EFFECT OF CRUDE OIL SPILLS ON THE MICROBIAL POPULATIONS OF SOILS FROM THE MACKENZIE DELTA, N.W.T.

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INTRODUCTION

Since the early 1900's microbial degradation of hydrocarbons has been acknowledged and studied by many workers. Through these studies there have been found more than 100 species of bacteria and fungi that are capable of utilizing hydrocarbons as their sole carbon source (Ellis and Adams, 1961). The apparent ubiquitous nature of these hydrocarbon-degrading microorganisms has led to studies over a wide range of environments.

The effects of crude oil spillage on microorganisms in soil and on soil biological activity has been examined by various workers. Plice (1948) found that an application of crude oil (1% by wt) to the soil surface caused an initial decline in the microbial population, but within a few months the population had increased to a level ten times the original. He also found that inundation of soil with crude oil preferentially promoted those species that are capable of utilizing hydrocarbons in their metabolism.

Haas *et al.* (1941) found that oil inundated soil was the best source of hydrocarbon-oxidizing microorganisms. These organisms are capable of attacking a wide range of hydrocarbons. Straight-chain paraffins are the most readily degradable fractions of crude oil. Stone *et al.* (1940) reported that fractions with high contents of cycloparaffins are not utilized as readily as the paraffins but more readily than the aromatics. Among the aliphatics, the straight-chained paraffins are more readily utilizable than the branched chains. The paraffins in the medium molecular weight range are oxidized more readily than either the low molecular weight or heavy paraffin fractions.

Schwendinger (1968) found that the microorganisms in recently re-

wet soils seemed to be more adversely affected by oil pollution than when more normal field conditions were present. He also found that the addition of oil almost completely inhibited microbial respiration for a few days but that this inhibition was followed by a burst of activity as the microbes adapted to their new substrate. Schwendinger also showed that microorganisms utilizing crude oil did so at accelerated rates when high moisture conditions of the soil existed.

Most species of hydrocarbon metabolizing microorganisms are aerobic but a few are anaerobic, e.g., *Clostridium* spp. Therefore, it seems that the optimal conditions for microbial degradation of crude oil in soil are good aeration and high moisture content of the soil. In addition, Schwendinger found that an increase in metabolic rate occurred in those soils inundated with crude oil where nitrogen and phosphorus supplements had been added.

Physical changesin soil properties, associated with oil inundation may have profound effects on the soil microflora. Schollenberger (1930) and Adams and Ellis (1960) showed that slightly acidic soil increased in pH when oil was applied. Harper (1939) and Plice (1948) showed that the carbon and nitrogen content increased in soils inundated with oil. Adams and Ellis (1960) found that oil contaminated soils had more available water and decreased bulk density.

McCown *et al.* (1971), in studies on a series of oil spills on both wet and dry soils at Barrow, Alaska, found an increase in the respiration rate of these soils from 0-200% over the control samples. Corresponding to this increase in respiration was a two- to three-fold increase in bacterial numbers and a general inhibition of fungal and algal growth.

The two overall effects of crude oil on the indigenous soil microbial population are:

1. certain microorganisms will be killed or inhibited by the crude oil,
2. certain chemo-organotrophic microorganisms will increase in numbers and activity due to their capability to metabolize hydrocarbons.

It is therefore essential to determine the total numbers of bacteria, total lengths of fungal mycelium and total activity of microorganisms in oil polluted soils when examining the role which soil microorganisms play in the decomposition of crude oil.

The increased intensity of crude oil exploration in the Canadian Arctic during recent years has led to widespread interest concerning the future of the north in terms of its development, ecology and environmental protection. Crude oil and gas have been discovered in the Arctic and overland pipelines seem to be the most likely means of transporting the products south. One proposed pipeline route seriously being considered would include passage along the MacKenzie River Valley. Thus in 1971 the study reported here was begun to evaluate the effects of crude oil spillage on the microbial population of certain soils in the MacKenzie River Delta.

MATERIALS AND METHODS

1. Sampling

a. Sampling Sites

Two sites in the MacKenzie River Delta, one at Tununuk Point (131°41'W, 69°01'N) and the other at Tuktoyaktuk (132°53'W, 69°25'N), were established by Dr. Ross W. Wein (Department of Botany, University of Alberta) in the spring of 1970 to study the effects of crude oil on vegetation. Therefore, it was decided to use these same oil treated

plots for the soil microbiological study reported here. The selection of these two sites was made on the basis of uniform vegetation, soil moisture and topography (Table 1, Plate 1).

b. Method of Crude Oil Treatment

On the dates indicated in Table 2, crude oil from Norman Wells, N.W.T., supplied by Imperial Oil Enterprises Ltd., was applied to the low-lying regions of the plots to simulate an oil spill. Oil was applied as a surface layer varying in depth from 0.25 cm to 1.50 cm depending on the depth of the active layer at the time of treatment. This variation was to ensure that the oil would percolate completely down the profile to the permafrost level (Bliss and Wein, 1972).

c. Sampling Techniques

The nature of the Tuktoyatuk site, together with considerable heterogeneity in soil conditions and organic matter accumulation within that site, caused considerable problems in sampling. It was decided to sample from the inter-hummock regions and to record variations in the wavy organic layer. At Tununuk, these sampling problems were reduced because the soil profile was much more homogenous as little variation occurred in the depth of the organic horizon.

Three sets of samples were taken during 1971 from both sites. The core samples were removed intact using an aluminum sampling tube (45 cm x 6 cm) which was driven down to permafrost. The samples were then wrapped in aluminum foil, placed in polythene bags and stored in a freezer prior to transport to the laboratory.

2. Microbial Analysis of Samples

Data on total numbers and respiration of soil bacteria and soil fungi and soil fungi were obtained, on both a seasonal and spatial basis, from soil samples in oil spill and control plots. The top 5 cm and bottom 5 cm of each core sample were examined. Total numbers of bacteria were determined using the dilution plate technique with peptone yeast extract (Difco) as the nutrient medium, three incubatory temperatures being used (0^{0}, 10^{0} and 20^{0}C). Total lengths of fungal mycelium were measured using the Jones and Mollison agar film technique (Jones and Mollison, 1948). Total soil respiration was determined using the Gilson differential respirometer at the same temperatures employed for the bacterial counting. In addition, various parameters influencing biomass and respiration of microorganisms in soil were measured. These included depth of active layer, organic matter content, soil moisture content, temperature and pH. In figs. 1-5 the 0 time represents samples taken approximately two hours after oil spillage thereby allowing sufficient time for the oil to percolate down the entire active layer.

RESULTS

1. Effect of Oil on Some Physical Properties of Soil

There was no significant difference in the soil moisture content of the control and oil-treated plots at Tuktoyaktuk. However, at Tununuk Point, where the soil was generally wetter than at Tuktoyaktuk (Table 3) the samples taken in July and August from the control soil were significantly wetter than the oil-treated samples. The moisture content, calculated on a dry wt basis, was greater in the top 5 cm of active layer than in the bottom 5 cm for both the sampling sites.

No significant differences were found in the organic matter content of the control and oil-treated plots at either Tuktoyaktuk or Tununuk Point, thus only results for the control soils are given (Table 3). However, due to the hummocky nature of the Tuktoyaktuk site, the depth of the organic horizon varied in thickness tremendously (Fig. 1). Whereas little or no organic material was incorporated into the soil profile at the hummock tops, the inter-hummock regions were almost entirely composed of organic materials to depths extending into the permafrost (Table 1). The organic matter content and depth of organic horizon were greater at Tununuk Point than at Tuktoyaktuk.

Upon examination of soil temperature and the depth of the active layer (Table 4) it was found that the level of permafrost was deeper for all three sampling times at Tuktoyaktuk than at Tununuk.

No significant differences in soil temperature between control and oil-treated plots were recorded at either site. However, soil temperature measurements taken in June and July showed the south-facing slopes of hummocks at Tuktoyaktuk were significantly warmer than the north-facing slopes. This increase in temperature may be due to warm flow of air from the south as all faces of the hummocks are equally exposed to the direct radiation of the sun as it travels around the horizon. The increased temperature will undoubtedly have profound effects on microbial activity.

In terms of soil pH, the response of the two sites to the oil treatment appeared slightly different. The Tuktoyaktuk control soil exhibited a pH of 6.5 and the addition of oil did not alter this. However, the Tununuk soil (initially pH 6.8) showed a slight increase in pH (to pH 7.0) following the application of oil.

2. Soil Respiration

a. Tununuk

Fig. 2 shows that for the June soil samples 0-5 cm deep in the active layer, incubated at 0°C, there was a significant decrease in respiration in the oil-treated samples as compared with control soil. However, for samples incubated at 10 and 20°C, there was significant increases in respiration in oil-treated samples as compared to control soil. Following this initial response to oil spillage the respiration rate in all oil-treated samples showed no further marked fluctuations up to 11 months following the oil treatment.

For the July soil samples, Fig. 2 indicates that the initial reaction to oil treatment at the three experimental temperatures was similar to the June samples, except that for the sample incubated at 0°C there was no significant difference in respiratory activity between the control and the treated samples.

The August soil samples at all the incubation temperatures showed decreases in respiratory rate immediately following oil treatment. However, within 1 month considerable increases in the respiratory rate of oil-treated samples as compared with control soil were registered in samples incubated at 10 and 20°C.

The rates of respiration of the oil-treated samples did not vary greatly for the three samplings as all seemed to achieve rates relatively steady of approximately 200 and 400 microliters oxygen consumed/g dry wt soil/6 hr at 10° and 20°C respectively. When these data were expressed per gram organic matter, no relative differences occurred among samples.

Data obtained using samples from the bottom 5 cm of the active layer are given in Fig. 3. For the July samples, a significant increase in

respiration in 10° and 20° was detected from the oil-treated samples over the control samples, however 13 months after the time of spillage there was an abrupt decrease in the respiration rate.

The August soil samples at all incubation temperatures showed little difference in respiration between the control and oil-treated samples. The oil-treated samples incubated at 20°C showed a significant increase in respiration over the control samples after 12 months since the time of spillage. However, as was recorded for the July samples, an abrupt decrease in respiration then occurred.

b. Tuktoyaktuk

Fig. 4 shows that for the June soil samples at 0-5 cm deep in the active layer, significant decreases in respiration of the oil-treated soils over the control occurred for all three incubation temperatures, except after 10 months since time of spillage at 10° and 20°C no significant differences between oil-treated and control samples were detected.

For the July soil samples, no significant differences were found between the oil-treated and control samples for 0°, 10° and 20°C. Following the initial application of oil, the respiratory rate did not change significantly with time.

The samples taken in August showed that the oil-treated samples incubated at 0° and 10°C were initially significantly lower in oxygen consumption than the control samples. After 3 months no significant differences occurred in respiration over the 13-month period since oil spillage among the oil-treated samples. The respiratory rates of the oil-treated samples showed no significant differences over the entire period.

The greatest rates of respiration for the oil-treated soil occurred in the samples taken in July while the control soil showed the highest respiratory rates in the June samples.

Fig. 5 shows that for the July soil samples at the bottom 5 cm of the active layer a significant increase in soil respiration occurred immediately after the oil application for the oil-treated samples incubated at 10^{0} and 20^{0}C. Two months after spillage, the oil-treated samples had decreased in soil respiration to the control level but, after 11 months, significant increases were found in the oil-treated samples as compared with control soil. The oil-treated and control samples incubated at 0^{0}C showed no significant differences between the control and oil-treated samples neither with respect to incubation temperature nor with the length of time since spillage.

3. Bacterial Numbers

   a. Tununuk Point

Table 5, giving data on bacterial numbers for the 0-5 cm section of the soil profile, shows that for the samples taken in June there were no significant differences between the control and oil-treated samples incubated at 0^{0}C. However, the oil-treated samples incubated at 10^{0}C show significant increases in bacterial numbers as compared to the control samples after 10 months since the time of spillage. Following an initial significant decrease in response to the oil treatment, the bacterial numbers in the oil-treated plots incubated at 20^{0}C showed no significant differences as compared with control soil.

The samples taken in July show that no significant differences in bacterial numbers occurred between oil-treated and control samples at

0°, 10° or 20°C, except 13 months after oil spillage the oil-treated samples incubated at 10° and 20° showed significant increases over the control samples. However, there were no significant differences found in bacterial numbers counted at 10°C as compared to 20°C.

For the August soil samples the bacterial numbers in the oil-treated soil initially increased significantly over the control samples in response to the oil application when incubated at 10° and 20°C. However, after 3 months since the time of spillage there were no significant differences at 20°C in bacterial numbers between the control and oil-treated samples but after 14 months the bacterial population of the oil-treated soil had significantly increased as compared to the control soils. There were no significant differences between samples incubated at 10° and 20°C.

The greatest number of bacteria were recorded in the samples taken in June while the fewest were found in the samples taken in July for both the oil-treated and control samples.

The number of bacteria in the bottom 5 cm of the profile (Table 6) show no significant differences between control and oil-treated soils at 0°C. However, the oil-treated samples incubated at 10° and 20°C show that 12 months after oil spillage there was a significant increase in bacterial numbers in the oil-treated samples as compared to the control samples. Following this a decrease occurred which showed no significant difference at 20°C from the control. The data from the August samples showed extreme variation occurring in bacterial numbers from both control and oil-treated samples and no significant differences were detected.

B. Tuktoyaktuk

Data for the 0-5 cm section of the profile (Table 7) indicate that for samples taken in June and incubated at 0°C, there were no significant differences in bacterial numbers between control and oil-treated soils. However, for the oil-treated samples incubated at 10° and 20°C there was a significant decrease in bacterial numbers as compared with the control.

The samples taken in July show extreme variation in bacterial numbers, however, 9 months after the time of spillage significant increases in oil-treated samples as compared with control samples occurred at 0°, 10° and 20°C incubation temperatures.

For the August samples, no significant differences were found in bacterial numbers between control and oil-treated soils except 10 months after spillage the oil-treated samples incubated at 10°C were significantly greater in bacterial numbers than the control samples.

The greatest number of bacteria in the oil-treated samples were found in the samples taken in July and the fewest in those taken in June. For the control samples, the highest bacterial numbers occurred in August and the lowest in July.

The bacterial numbers for the bottom 5 cm (Table 8) from the July samples indicated significant increases occurred 9 months after oil spillage for the oil-treated samples incubated at 0°C and 12 months after oil spillage for the oil-treated samples incubated at 10° and 20°C.

The samples taken in August showed that the bacterial numbers in the oil-treated soils increased significantly 13 months after the time of oil spillage at 10° and 20°C incubation temperatures. The number of

bacteria incubated at 0°C fluctuated in response to the oil treatment throughout the period of time over which numbers were recorded.

The highest numbers of bacteria occurred in the August samples for both the control and oil-treated plots.

4. Total Length of Fungal Mycelium/g dry wt Soil

a. Tununuk

The fungal component of the 0-5 cm section of the soil profile decreased soon after oil was applied (Fig. 5). Two months after treatment the total length of fungal mycelium per gram dry wt soil remained the same as at 0 time but 3 months after oil treatment hyphal lengths were the same as those found in control soils and remained consistent over the remaining 15-month interval.

For the bottom 5 cm of the profile there was a significant increase in hyphal length in the oil-treated samples after 1 month since spillage but this decreased to the level of the control after 15 months.

b. Tuktoyaktuk

For the 0-5 cm section of the profile there was a significant decrease in length of mycelium after 3 months since spillage in the oil-treated samples as compared with the control. Recovery by the fungi was not evident until 13 months after treatment after which time mycelial lengths remained at the same level as the control.

The bottom 5 cm of the profile showed a significant increase in mycelium in the oil-treated samples over the control 14 months after the time of oil application.

DISCUSSION

The crude oil treatments described above affected various soil properties. The decrease in moisture recorded in the Tununuk oil-treated samples, as compared to control soils, was due to increased radiation absorption resulting from the blackening of the soil surface by the crude oil treatment. However, the degree of plant cover was also a major factor affecting the moisture regime at both Tununuk and Tuktoyaktuk (Wein, pers. comm.). The higher moisture content recorded in the Tununuk soils as compared to the Tuktoyaktuk soils was attributed to the distinct microtopographical characteristics of the two study sites. The Tununuk site is situated in a poorly drained, low-lying area whereas at Tuktoyaktuk the study site is located on a raised plain with better drainage than at Tununuk.

The fact that the active layer at Tuktoyaktuk was deeper at all three sampling times than at Tununuk was because the insulating organic mat of vegetation and litter was thinner at Tuktoyaktuk than at Tununuk thereby allowing deeper penetration of heat.

The neutralizing effect of the oil on the slightly acidic Tununuk soil agreed with the findings of Schollenberger (1930) and Ellis and Adams (1960). They suggested that products of hydrocarbon saturation may buffer the soil toward neutrality rather than increase the alkalinity of the soil.

The inhibitory effect on the respiration rate at 0°C in the June oil-treated samples for the 0-5 cm horizon at Tununuk and the increased rate for the 10° and 20°C oil-treated samples from the same horizon suggests that the psychrophilic and mesophilic segments of the microbial population react differently to the introduction of crude oil to the soil. In June and July the response of the soil microflora to the oil

treatment occurred immediately following spillage, thus any lag phase appeared to be of very short duration.

Respiratory rates for the 0-5 cm section of the soil profile at Tununuk did not change significantly throughout the three sampling times indicating little seasonal variation in both the oil-treated and control samples. However, this is not to say that there is no seasonal variation in soil respiration at this site, only that the number of sampling times was not sufficient to detect these variations. However, the fact that the microflora showed no immediate response, as indicated by respiration measurements, to the oil spilled in August (0 time), is indicative of the microbes adaptability to the cooler field temperatures associated with the approach of winter. It is, therefore, expected that because of the wide range of field temperatures associated with these tundra soils, extreme seasonal variation in microbial activity would occur.

It has been demonstrated that the highest rates of respiration for the 0-5 cm section of the soil profile occur at 20°C for all samples examined. Thus, assuming that increased respiration rates of oil-treated soils as compared with control soils are indicative of microbial degradation of crude oil, the rate of oil decomposition is temperature dependent, being greatest at 20°C for the temperatures used.

Although many species of microorganisms may be involved in the degradation of crude oil, it is generally found that similar catabolic pathways are employed in the degradation of individual fractions (Quayle, 1967). It has been shown that microorganisms preferentially attack paraffins fractions of crude oils over the other saturates present in crude

petroleum. If various fractions of the crude oil were susceptible to microbial degradation during the periods of time at which the soil samples were examined, then there was a similar respiratory response by these microorganisms to the various crude oil fractions. Therefore, in terms of oxygen consumption, there has been no indication of preferential microbial utilization of any one crude oil fraction. However, the other possibility could be that the organisms are responding to the same fraction(s) over the entire time interval.

In the bottom 5 cm of the active layer at Tununuk the control soil samples studied did not demonstrate statistically different respiration rates at 0°, 10° or 20°C. However, there was a significant increase in respiration in the oil-treated soils as compared with the control at 10° and 20°C for the samples taken in July. This illustrates that the segment of the microbial population that is able to utilize crude oil responds more favourably to the higher temperature.

The abrupt decrease in respiration following the twelfth month reflected the shallow active layer (5 cm) present where the oil was spilled (June, 1970). Hence, when this oil-treated plot was sampled at a later date (July, 1971), when the active layer was much thicker, the decrease in microbial activity was attributed to the absence of crude oil.

The ability of the soil microflora to metabolize crude oil appeared to have diminished in the soil samples collected in August, 1971. The lower field temperatures and a general adaptation by the organisms to the oncoming winter conditions was probably responsible for this.

At Tuktoyaktuk, the microbial activity recorded in June from the 0-5 cm section of the profile indicated that a longer period of adapta-

tion by the soil microflora to the crude oil substrate was necessary. However, the samples taken in July showed no apparent change in respiratory activity over the entire period during which measurements were taken. The August samples showed a similar pattern to those samples taken in June except the adaptation time was shorter. Therefore, it seems that the samples taken from this site have shown that seasonal variation in microbial activity will have a profound effect on the ability of the soil microflora to degrade the oil. It appears that the fastest rates of crude oil degradation occur in July..

These samples have also illustrated that after a period of adaptation the segment of the microbial population that is able to tolerate and/or metabolize the crude oil, does so with no statistically significant change in total soil respiration.

The July samples taken from the bottom 5 cm of the active layer at Tuktoyaktuk showed an immediate stimulatory response by the soil microflora to the oil treatment. This was probably related to an increase in soil temperature during this period when unusually high temperatures persisted for a number of days. After 11 months since the time of oil spillage, the soil microorganisms seemed to have adapted to the new substrate and were metabolizing at a significantly faster rate than in the control samples. The rates of respiration were temperature dependent. However, in August, while the same general pattern of microbial activity occurred as in July, there was no dependence upon temperature by the soil microflora and very low levels of activity were recorded. It is, therefore, evident that microbial degradation of the crude oil in the lower horizons will proceed at a very slow rate due to the cool temperatures associated

with this depth of the active layer.

It is difficult to make meaningful generalizations from the data on bacterial numbers in the various soils because of the high standard errors associated with such numbers, this being an effect of the extreme heterogeneity of the soil conditions encountered at the sampling sites. However, certain trends did seem evident. Firstly, there was an overall increase in bacterial numbers in the oil-treated samples as compared with the control for those soils incubated at 10° and 20°C. However, while respiratory rates for the 0-5 cm layer at Tununuk were immediately stimulated by application of the oil, the number of bacteria present in the soil increased only after a period of adaptation.

Secondly, an analysis of correlation showed a significant ($\alpha = 0.05$) correlation coefficient of 0.93 when bacterial numbers and respiration were compared for the bottom layer from the August samples at Tuktoyaktuk incubated at 20°C. All other correlations between bacterial numbers and respiration were not significant.

This suggests that decomposition of the oil, as monitored by increased respiration, proceeded almost immediately upon treatment, but only a segment of the indigenous microbial population was capable of microbial degradation of the oil. The remainder of the population was either induced into a state of dormancy or killed by the presence of the oil. The hydrocarbon degrading organisms then proceeded to increase in numbers due to crude oil enrichment.

In general, both total soil respiration and bacterial numbers were greater at Tuktoyaktuk than at Tununuk for the 0-5 cm layer. This could have been related to the high soil moisture occurring at Tununuk which may have decreased aeration.

A segment of the total fungal component of the soil was lost imme-

diately following oil inundation at Tununuk. This may have been caused by lysis of the mycelium by the oil as it is inconceivable that in a few hours vast amounts of hyphae could disappear via metabolic processes.

The recovery of mycelium to amounts found in the control was much more rapid at Tununuk than at Tuktoyaktuk, but the standing fungal crop at Tuktoyaktuk was approximately three times greater than that at Tununuk. This illustrated the presence of live mycelium in the oil-contaminated soils suggesting an integral role of soil fungi in the decomposition of crude oil. Further evidence elucidating this possibility occurred at the bottom 5 cm of the active layer at Tuktoyaktuk where a gradual increase in fungal mycelium occurred in the oil-treated plots.

The many questions which have been raised throughout the course of the experimental work reported here can only be properly answered by combining chemical analytical techniques (such as the use of gas liquid chromatography, fluorimetry, and mass spectrometry in the study of soil extracts) with studies of general soil microbiology. Such combined studies are presently in progress.

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TABLE 1. Description of Study Sites: Tuktoyaktuk and Tununuk Point

	Location	
	Tuktoyaktuk	Tununuk Point
Plant Community	*Salix* heath shrub	*Eriophorum* - *Carex* tussocks
Soil Surface Characteristics	Small frost hummocks	Low center polygons
Depth of Permafrost (cm)		
June	20 (hummock top) 10 (inter-hummock)	5
July	50 (hummock top) 30 (inter-hummock)	20
Depth of Organic Horizon (cm)	0-2 (hummock top) 15-20 (inter-hummock)	10

TABLE 2. Amounts of Oil Applied

Location	Surface Depth Oil (cm)	Date of Application
Tuktoyaktuk	1.0	July 19, 1970
	1.5	August 17
	1.0	October 18
	1.0	June 3, 1971
	1.5	July 25
	1.0	August 26
Tununuk Point	1.0	June 22, 1970
	1.5	July 21
	1.0	June 4, 1971
	1.5	July 26
	1.0	August 27

TABLE 3. Organic Matter and Soil Moisture Content for Control Plots

Location	Depth (cm)	Organic Matter (loss on ignition/od wt)[a]			% Moisture (od wt)		
		June	July	Aug.	June	July	Aug.
Tuktoyaktuk	0-5	76	76	66	331	261	251
	bottom 5	-	11	22	-	49	105
Tununuk Point	0-5	70	74	67	383	305	347
	bottom 5	0	27	27	-	118	99

[a] 600°C for 3 hours

TABLE 4. Soil Temperature for Control Plots showing Depth of Active Layer

	Temperature (°C)			
Depth of Profile (cm)	June		July	
	Tun.	Tuk.	Tun.	Tuk.
0	15	15	26.5	22.5
1			19	21
5	0	3	9	12
10		0		
15	p[a]		6.5	8.5
20		p	3.5	5.5
25			0	
30	p	p	p	
	p	p	p	p
	p	p	p	p

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[a] Permafrost

TABLE 5. Number of Bacteria at Tununuk for the 0-5 cm Section of the Soil Profile

Length of Time since Oil Spillage (months)	No. of Bacteria/g dry wt soil x 10^6 0°C	10°C	20°C
	samples taken in June 1971		
Control	6 ± 3[a]	17 ± 6	339 ± 60
0	3 ± 1	43 ± 34	58 ± 28
10	22 ± 6	162 ± 40	226 ± 59
11	21 ± 12	180 ± 54	1065 ± 829
	samples taken in July 1971		
Control	.4 ± .2	12 ± 5	18 ± 4
0	.1 ± .1	9 ± 3	28 ± 15
2	.2 ± .1	12 ± 5	35 ± 7
12	8 ± 2	84 ± 58	108 ± 79
13	.1 ± 0	274 ±135	311 ± 142
	samples taken in August 1971		
Control	1 ± .6	12 ± 4	37 ± 13
0	29 ± 15	312 ±129	550 ± 176
1	12 ± 7	482 ±326	571 ± 334
3	2 ± 1	78 ± 36	198 ± 117
13	3 ± 1	28 ± 12	60 ± 12
14	78 ± 7	312 ±145	509 ± 262

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[a] Standard error of the mean.

TABLE 6. Number of Bacteria at Tununuk for the Bottom 5 cm of the Soil Profile

Length of Time since Oil Spillage (months)	No. of Bacteria/g dry wt soil x 10^6 $0^{\circ}C$	$10^{\circ}C$	$20^{\circ}C$
	samples taken in July 1971		
Control	4 ± 1[a]	2 ± 2	20 ± 16
0	.3 ± .2	1 ± 1	6 ± 3
2	.1 ± .1	14 ± 9	10 ± 0
12	2 ± 2	93 ± 1	63 ± 2
13	.5 ± .4	19 ± 2	27 ± 6
	samples taken in August 1971		
Control	.5 ± .3	42 ± 39	25 ± 16
0	41 ± 14	188 ± 77	610 ± 143
1	1 ± 0	33 ± 12	72 ± 1
3	.2 ± .1	71 ± 63	71 ± 32
13	8 ± 8	84 ± 77	98 ± 76
14	4 ± 2	22 ± 10	75 ± 51

[a] Standard error of the mean

TABLE 7. Number of Bacteria at Tuktoyaktuk for the 0-5 cm Section of the Soil Profile

Length of Time since Oil Spillage (months)	No. of Bacteria/g dry wt soil x 10^6		
	0°C	10°C	20°C
		samples taken in June 1971	
Control	.3 ± .1[a]	151 ± 79	313 ± 192
0	.1 ± .1	33 ± 8	126 ± 62
7	.2 ± .1	9 ± 3	34 ± 13
10	26 ± 21	28 ± 22	57 ± 19
11	.3 ± .1	17 ± 6	29 ± 5
		samples taken in July 1971	
Control	3 ± 2	32 ± 13	170 ± 70
0	.3 ± .3	2 ± 1	6 ± 2
2	1 ± 1	128 ± 121	101 ± 87
9	10 ± 0	269 ± 180	671 ± 357
11	28 ± 7	2092 ±1418	1770 ± 753
12	387 ±348	506 ± 345	1679 ± 602
		samples taken in August 1971	
Control	2 ± .1	108 ± 88	412 ± 331
0	11 ± 9	90 ± 44	178 ± 110
1	16 ± 9	70 ± 52	83 ± 34
3	17 ± 16	123 ± 36	86 ± 15
10	9 ± 5	608 ± 212	711 ± 239
12	18 ± 10	435 ± 212	895 ± 218
13	7 ± 5	89 ± 35	710 ± 427

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[a] Standard error of the mean

TABLE 8. Number of Bacteria at Tuktoyaktuk for the Bottom 5 cm of the Soil Profile

Length of Time since Oil Spillage (months)	No. of Bacteria/g dry wt soil x 10^6		
	0°C	10°C	20°C
		samples taken in July 1971	
Control	.3 ± .2[a]	6 ± 1	14 ± 4
0	.04 ± .01	6 ± 2	15 ± 6
2	.1 ± .06	3 ± 5	5 ± 3
9	2 ± 1	7 ± 2	17 ± 10
11	1 ± .4	6 ± 4	22 ± 5
12	4 ± 2	17 ± 5	45 ± 10
		samples taken in August 1971	
Control	.2 ± .1	33 ± 1	34 ± 9
0	2 ± 2	13 ± 1	22 ± 5
1	20 ± 16	46 ± 28	63 ± 21
3	.4 ± .2	18 ± 1	32 ± 2
10	.6 ± .5	22 ± 8	28 ± 4
12	5 ± 3	20 ± 3	37 ± 13
13	14 ± 7	142 ± 64	120 ± 55

[a] Standard error of the mean

ILLUSTRATIONS

FIG. 1 Top photo

Profile of frost boil hummock at Tuktoyaktuk. Scale in cm.

Bottom photo

Soil profile at Tununuk Point. Scale in cm.

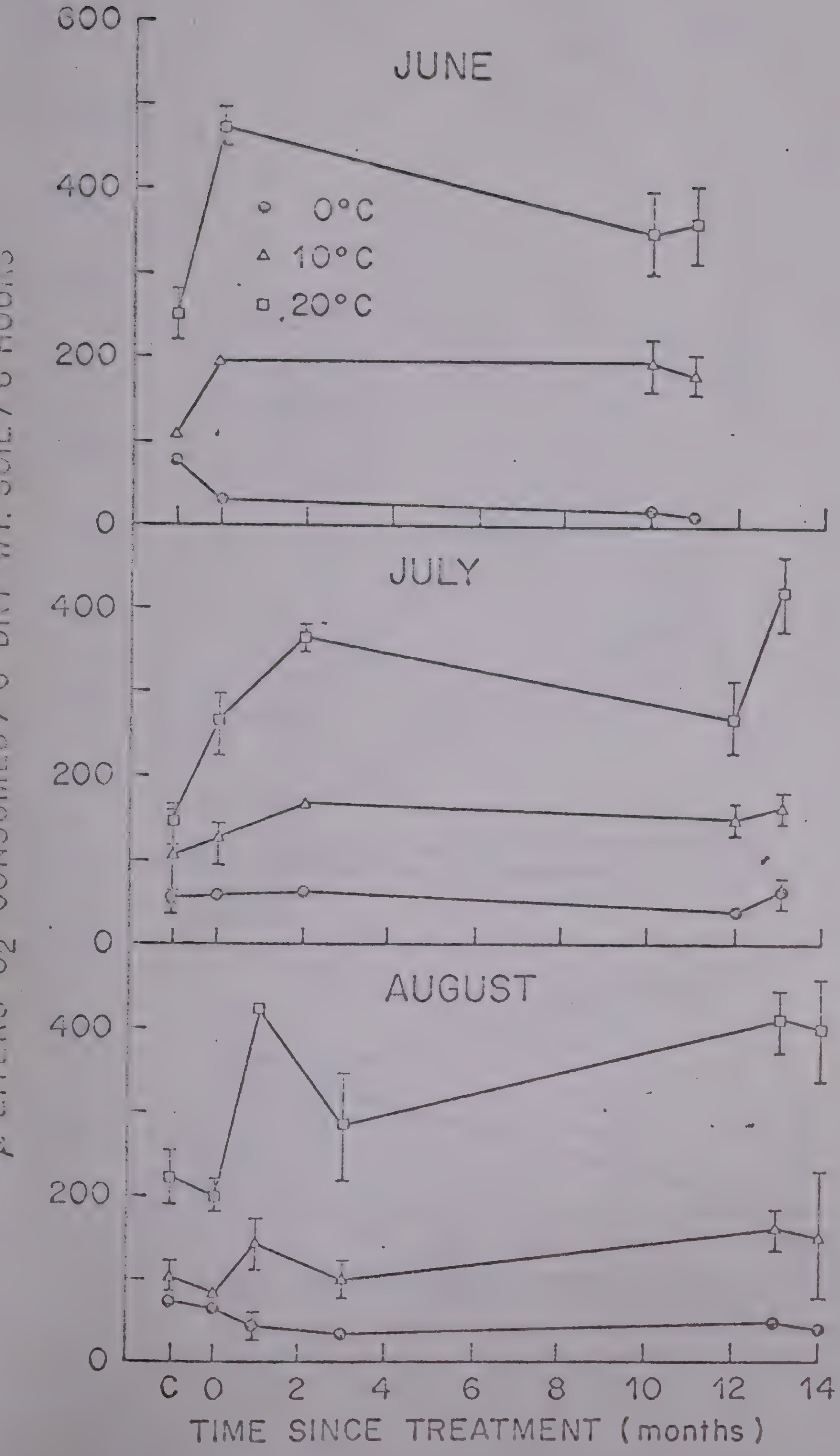
FIG. 2 Respiration rates at Tununuk Point from the top 5 cm layer of soil incubated at three temperatures. Samples were taken in June, July and August 1971. The variation shown is standard error of the mean.

FIG. 3 Respiration rates at Tununuk Point for the bottom 5 cm layer of soil incubated at three temperatures. Samples were taken in July and August 1971. The variation shown is standard error of the mean.

FIG. 4 Respiration rates at Tuktoyaktuk for the top 5 cm layer of soil incubated at three temperatures. Samples were taken in June, July and August 1971. The variation shown is standard error of the mean.

FIG. 5 Respiration rates at Tuktoyaktuk for the bottom 5 cm layer of soil incubated at three temperatures. Samples were taken in July and August 1971. The variation shown is standard error of the mean.

FIG. 6 Total lengths of fungal mycelium. The variation shown is standard error of the mean.



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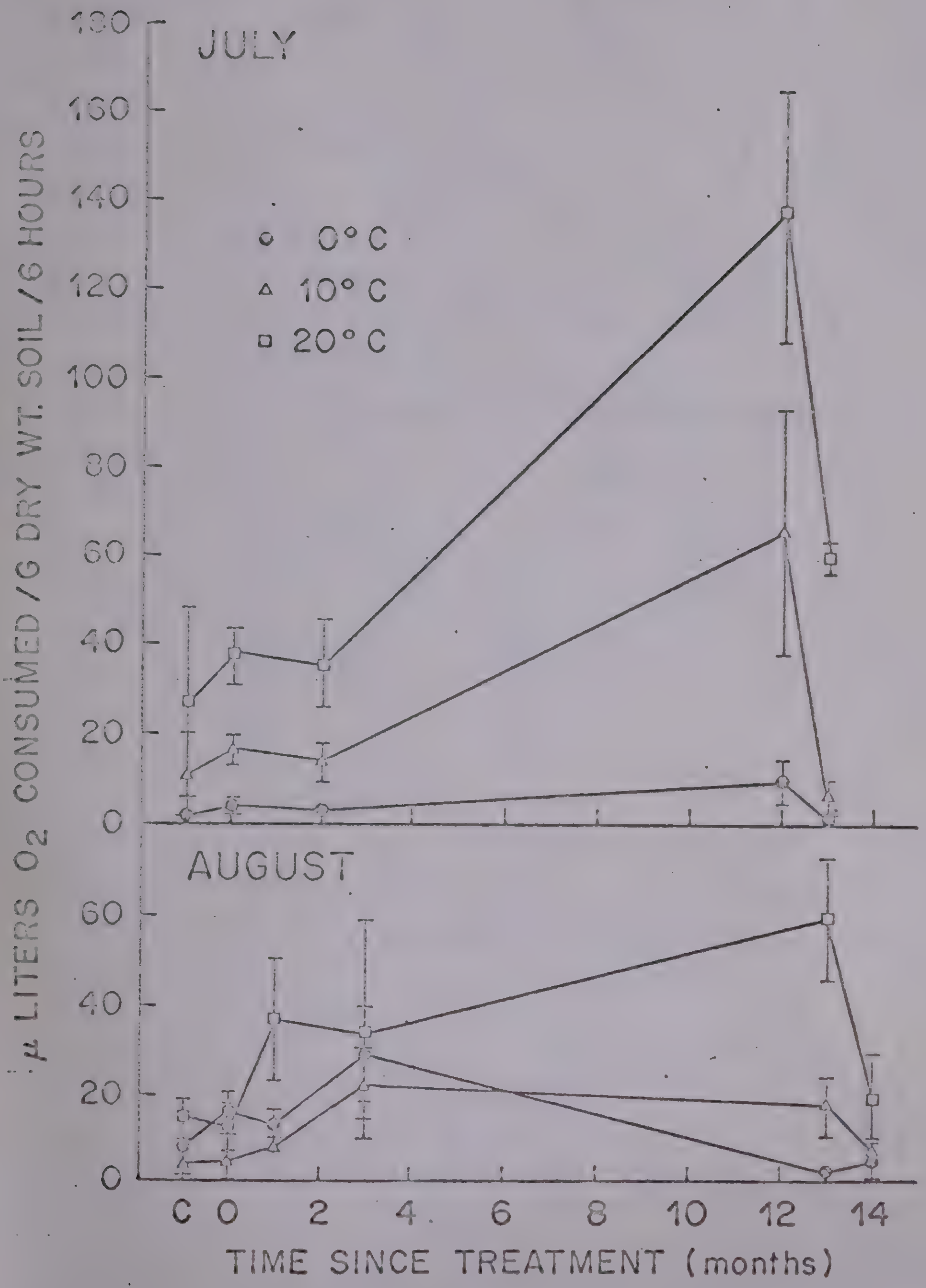

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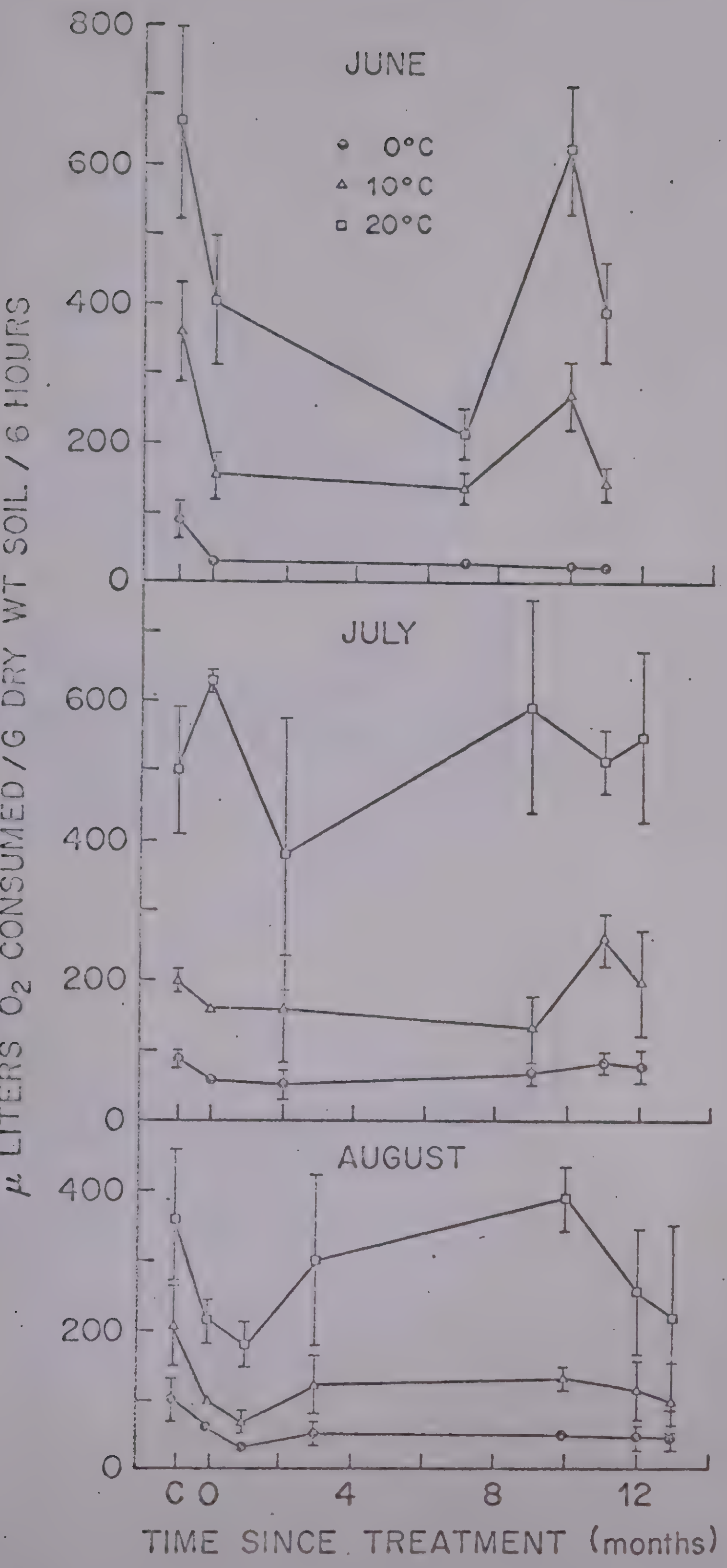

Fig. 4

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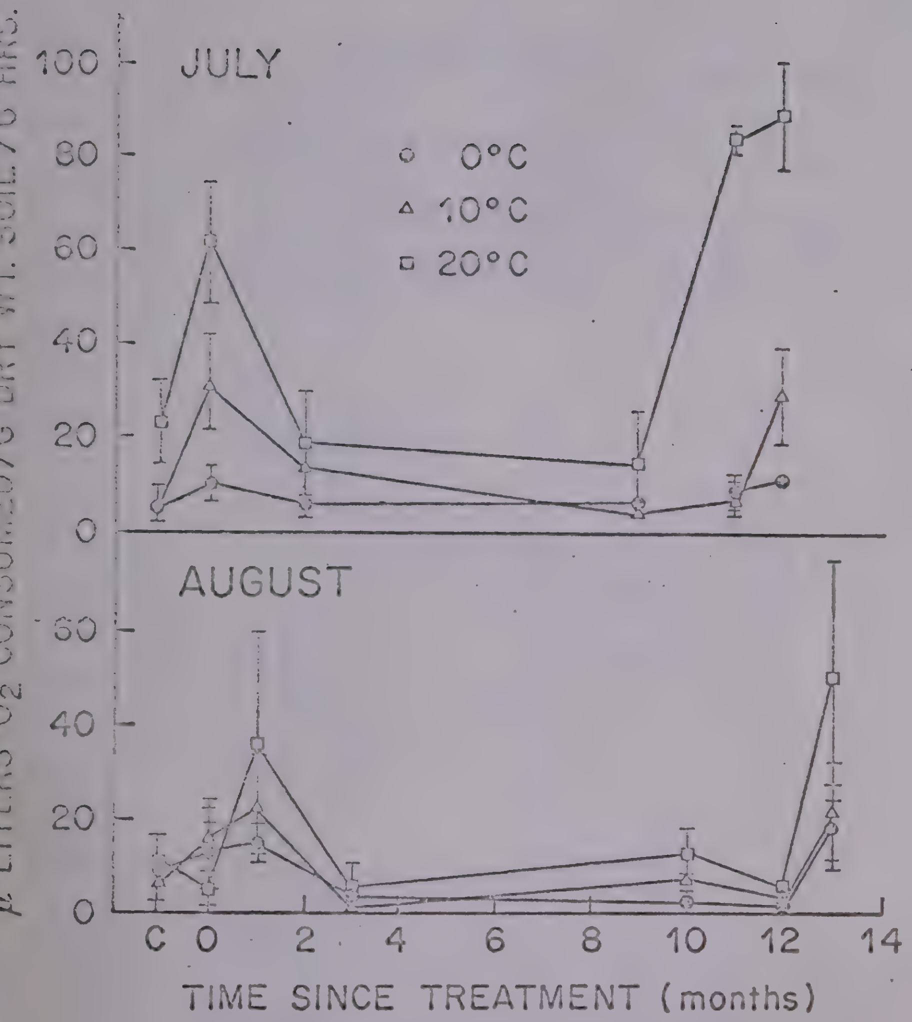
The effect of crude oil spills on the microbial population of soils from the Mackenzie Delta, NWT



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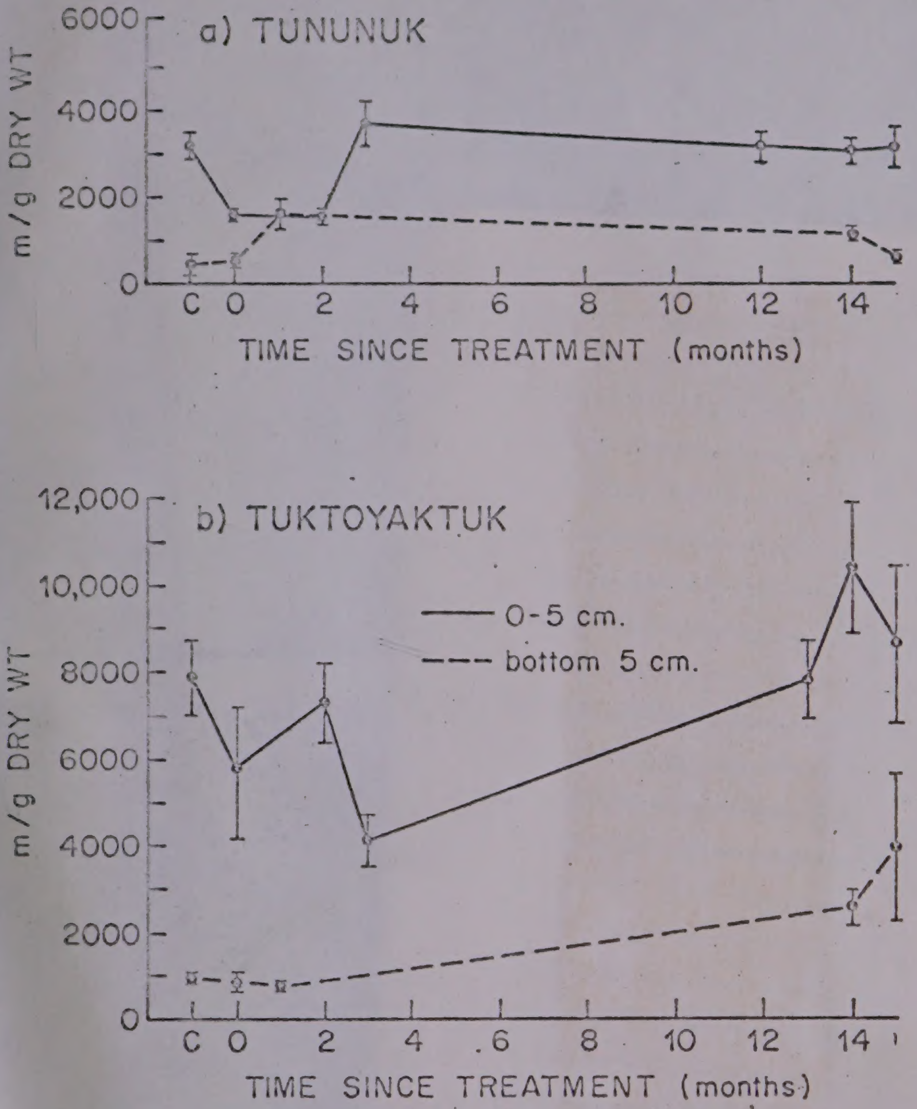

Fig. 6

Gossen + Parkinson

The effect of crude oil spills on the microbial population of soils from the Mackenzie Delta, NWT

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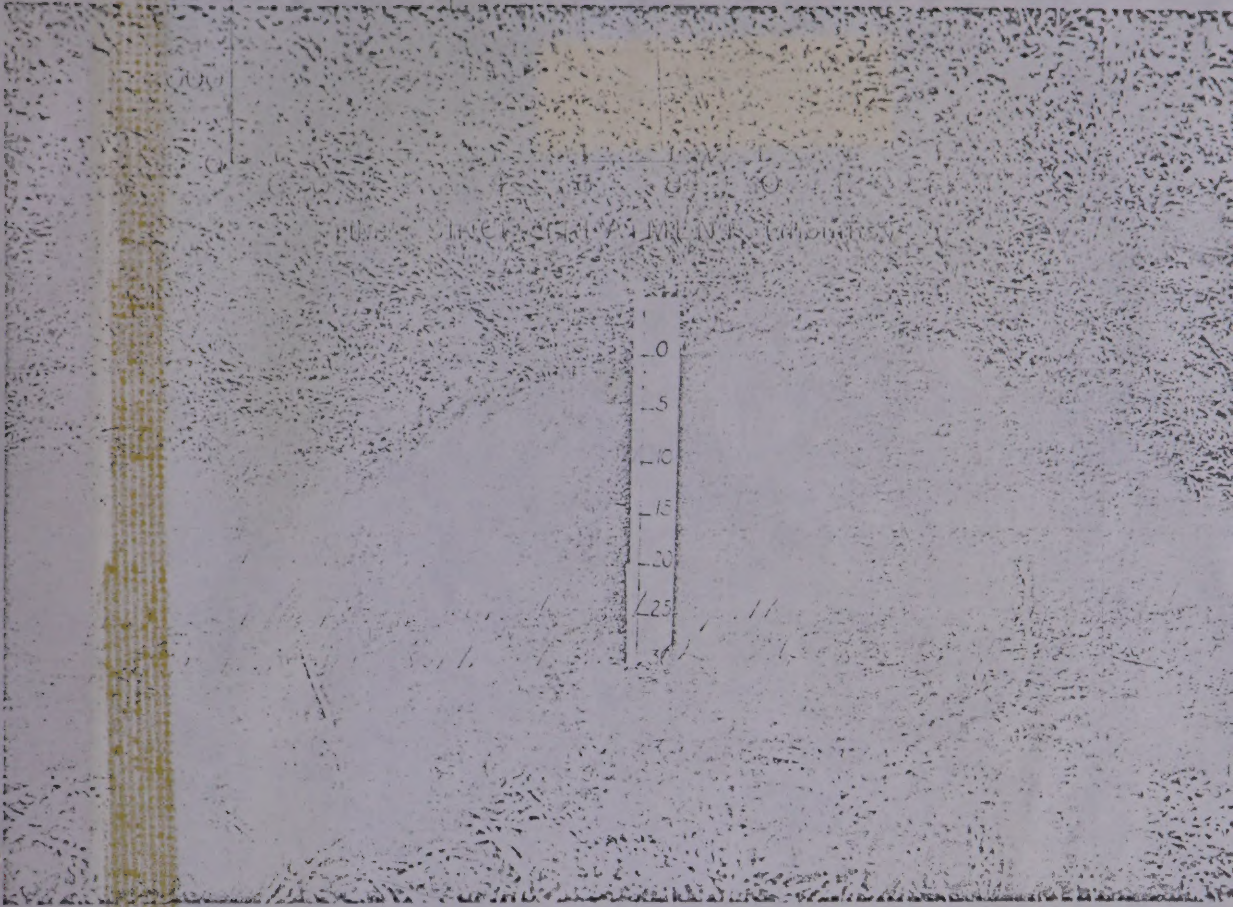
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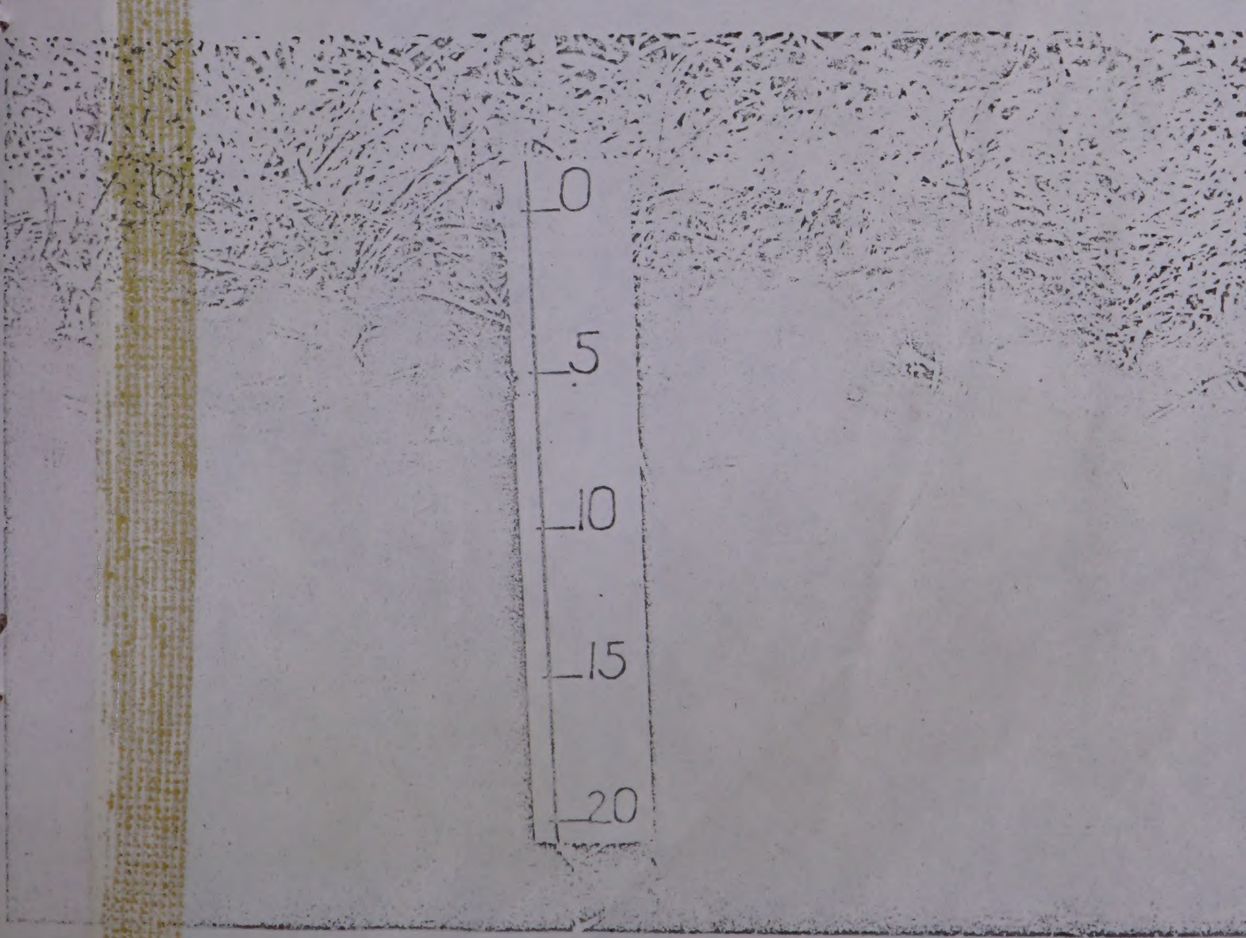
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